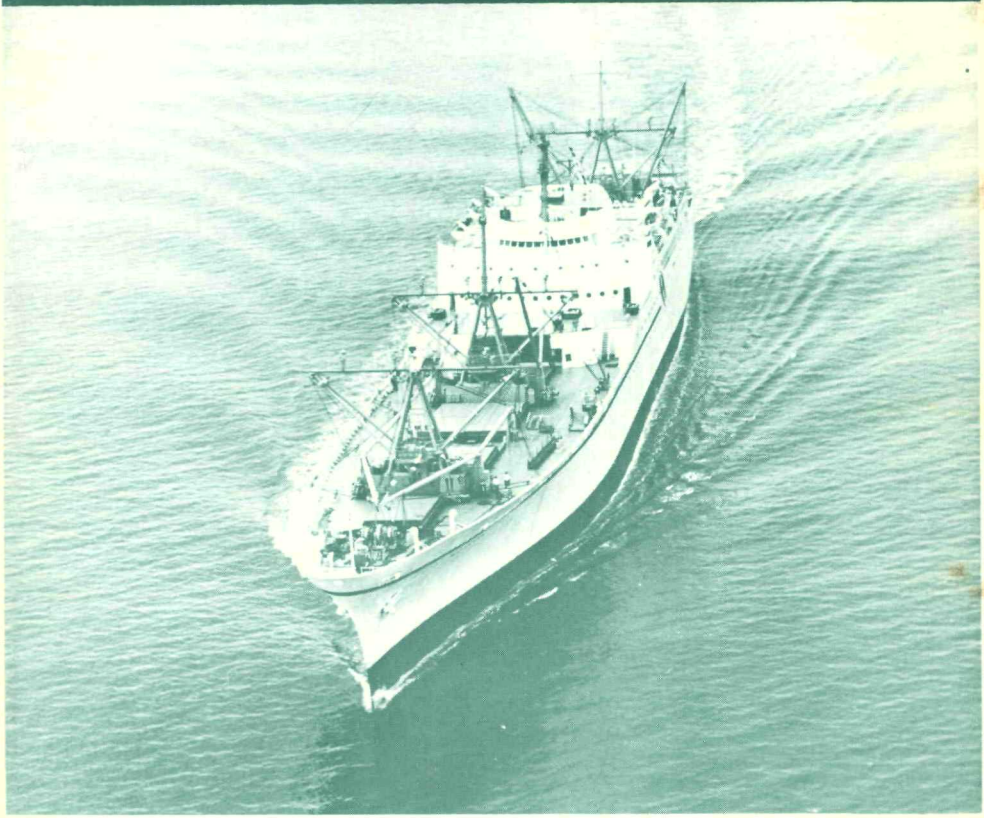
NUCLEAR POWER and MERCHANT SHIPPING



U.S. ATOMIC ENERGY COMMISSION / Division of Technical Information

ONE
OF A SERIES ON
UNDERSTANDING THE ATOM

UNITED STATES
ATOMIC ENERGY COMMISSION

Dr. Glenn T. Seaborg, Chairman
James T. Ramey
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Nuclear energy
is playing a vital role
in the life of
every man, woman, and child
in the United States today.
In the years ahead
it will affect increasingly
all the peoples of the earth.
It is essential
that all Americans
gain an understanding
of this vital force if
they are to discharge thoughtfully
their responsibilities as citizens
and if they are to realize fully
the myriad benefits
that nuclear energy
offers them.

The United States
Atomic Energy Commission
provides this booklet
to help you achieve
such understanding.

Edward J. Brunenkant
Director
Division of Technical Information

NUCLEAR POWER and MERCHANT SHIPPING

by Warren H. Donnelly

CONTENTS

SHIPS AND MEN AND ENERGY 1
- The Atom at Sea: Its Promise 3
- Taking the Atom to Sea 5
- How Nuclear Energy Is Produced 7

THE NS *SAVANNAH* 8
- Description 12
- Comparison with Conventional Ships 13

POWER FOR THE NS *SAVANNAH* 14
- Fuel 14
- Control Rods 16
- Pressure Vessel; Steam Generation; Containment Vessel . . 17
- Shielding; Radioactive Wastes 19
- Emergency Power 20

FOREIGN TRADE AND FISSION 20
- Exports, Imports, and Economic Health 20
- The American Merchant Marine 22
- Foreign Trade 23

SPECIAL CONSIDERATIONS 25
- Safety; Servicing 26
- Port Acceptance 27
- Training 29
- Insurance 30

WORLD NUCLEAR SHIP DEVELOPMENT 31

LOOKING AHEAD 35

SUGGESTED REFERENCES 37

United States Atomic Energy Commission
Division of Technical Information
Library of Congress Catalog Card Number: 64-61901
1964; 1965(Rev.)

On the cover is a picture of the N.S. *Savannah,* the first cargo-passenger ship to be driven by nuclear power.

WARREN H. DONNELLY's career with the Federal Government illustrates well the variety of assignments and experience to be found in modern civil service. Having studied physics in college, he began work as a junior engineer with Western Electric Corporation. Several years later he joined the U. S. Atomic Energy Commission at its New York Operations Office as an administrative assistant in a small laboratory. Later he became a negotiator for AEC research and development contracts and then became director of a technical services division. This work stimulated his interest in administration, and he enrolled in New York University's Graduate School of Public Administration and received his master's degree in public administration and his Ph.D. degree. In 1963 he transferred to the AEC Washington Headquarters, working there to encourage commercial use of ideas and inventions arising from atomic research and development. Then in 1965, shortly after the Science Policy Research Division was established in the Legislative Reference Service of the Library of Congress, he joined its staff to provide members of Congress with information to assist them with issues of public policy relating to science and technology.

NUCLEAR POWER and MERCHANT SHIPPING

By WARREN H. DONNELLY

SHIPS AND MEN AND ENERGY

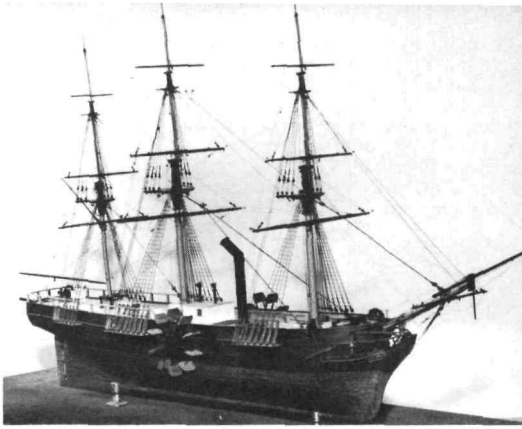
From the earliest times man has turned to the waters to carry goods and passengers. Through the centuries he has harnessed many different forms of energy to move his cargoes on rivers, bays, and seas. He has built rafts to move upon the currents, galleys rowed by men, sailing ships of great variety to tap the strength of the winds, and steam and motor ships driven by the energy of coal and oil. Now man is ready to use the primordial source of power, the conversion of matter into energy, to send his merchant vessels on their voyages.

Already matter is being converted into energy at sea. Beneath the surface, submarines are using energy from the atom; on the surface, an aircraft carrier, a cruiser, a frigate, a merchant ship, and an icebreaker all are exploiting this new form of energy. Each passing day brings added information for use by engineers, designers, builders, economists, lawyers, insurance agents, labor leaders, and the many others who eventually will determine how and when nuclear power will be used by the world's merchant marine.

This booklet tells about the use of nuclear energy for merchant ships. It explores its advantages and disadvantages, describes a nuclear merchant ship, speculates about the effect of nuclear power upon seaborne trade, and discusses some of the differences between conventional and nuclear merchant ships.

Man has profited whenever he found new sources of energy to speed the movement of passengers and goods upon the seas. His efforts reached one culmination in the nineteenth century when swift and wonderfully graceful American clipper ships sailed the long reaches of the oceans. Yet the heyday of these ships lasted less than the lifespan of a man. Long before the superb *Flying Cloud* made her record 374 miles in 24 hours under sail on her famous passage from New York to San Francisco in 1851, a noisy, dirty, dangerous machine—the steam engine—was taking to the seas and soon was to relieve mariners from their age-old dependence on the favor of the winds.

Early in 1819 a small sailing ship, the *Savannah,* made the first crossing of the Atlantic with the assistance of a steam engine. Hers was a daring pioneering accomplishment sponsored by American merchants. But the shipping industries of the world were not ready for her, and the SS *Savannah* (the letters SS stand for "steamship") was a commercial failure, ending her days as a simple sailing ship. Change came slowly, and not until 20 years later did the first vessel, the British ship *Sirius,* cross the ocean propelled entirely by steam. This venture pointed the way for the development of the great British steam merchant ship fleet.



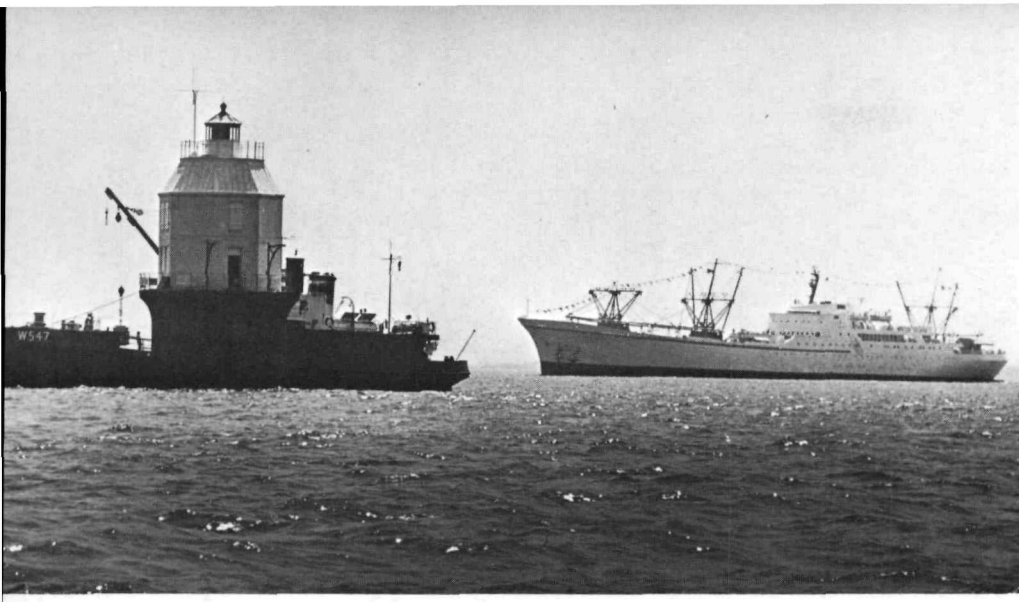
The SS Savannah *was a technological pioneer of the nineteenth century that demonstrated the use of steam on the high seas. A model of the historic vessel like the one on this page is displayed in the main dining room of the new NS* Savannah. *A model of the NS* Savannah, *which is now demonstrating nuclear-powered ship propulsion, is shown on the left-hand page.*

Today the step from oil to nuclear fuel is as great an experiment as was that from sail to steam. It remains to be seen whether nuclear power will offer advantages sufficient to justify shipowners' building and operating nuclear ships to replace present fleets. Steamships cost more to build and more to operate than sailing ships. Nevertheless in the early days of steam, merchants began to ship the best and most profitable of their cargoes in steamships. Why? Because steam offered, at a price, the reliability demanded by the booming commerce of the nineteenth century. Today a new technological pioneer, the merchant ship NS *Savannah* (the letters NS stand for "nuclear ship"), is demonstrating nuclear power at sea. Flying the American flag, she is an experiment: A merchant ship with nuclear engines, whose job is to demonstrate to the world's shipping industries what nuclear power can do.

The Atom at Sea: Its Promise

Why take nuclear power from snug stationary power plants ashore and send it to sea? What advantages are expected which justify the strenuous, expensive engineering effort and the investment of public and private funds? They are four: freedom from frequent refueling, low fuel costs, higher speeds, and greater cargo capacity.

Freedom Just as the steamboat freed merchant shipping from dependence on wind and tide, so nuclear power can free merchant ships from dependence on the availability of fuel at remote ports of call. A nuclear merchant ship can sail 2 to 5 years without taking on fresh fuel. This will give



The Atom at Sea: The NS Savannah, *world's first nuclear-powered merchant ship, passes the Baltimore Lighthouse in Chesapeake Bay, Maryland, which is the first lighthouse in the world to be operated by an atomic generator. A Coast Guard buoy tender is behind the lighthouse installing the generator.*

nuclear ships the limitless range of the sailing ship and the independence and reliability of the steamship. This freedom of operation could open new trade routes throughout the world.

Low Fuel Costs The owner of a nuclear ship can expect its fuel costs to be less than the costs of oil for a conventional ship. Since all the fuel needed for several years can be bought at one time, the owner need not consider costs of fuel in remote ports nor worry about fluctuating prices.

Higher Speeds In view of the independence of fuel supply and lower fuel costs, it is probable that a shipowner can afford to order nuclear ships with more powerful engines and sail them at higher speeds over longer routes than would be practicable for conventional ships. Some marine architects and economists believe that higher speed express service can make new types of cargo economically feasible for movement by sea. These promised advantages could change the pattern of maritime trade by encouraging new designs for merchant ships and improved cargo handling techniques that would cut costs and increase the delivered value of perishable items.

Greater Cargo Capacity Because the fuel in a nuclear ship is compact and long-lasting, much of the capacity normally preempted by fuel can be converted to revenue-producing cargo.

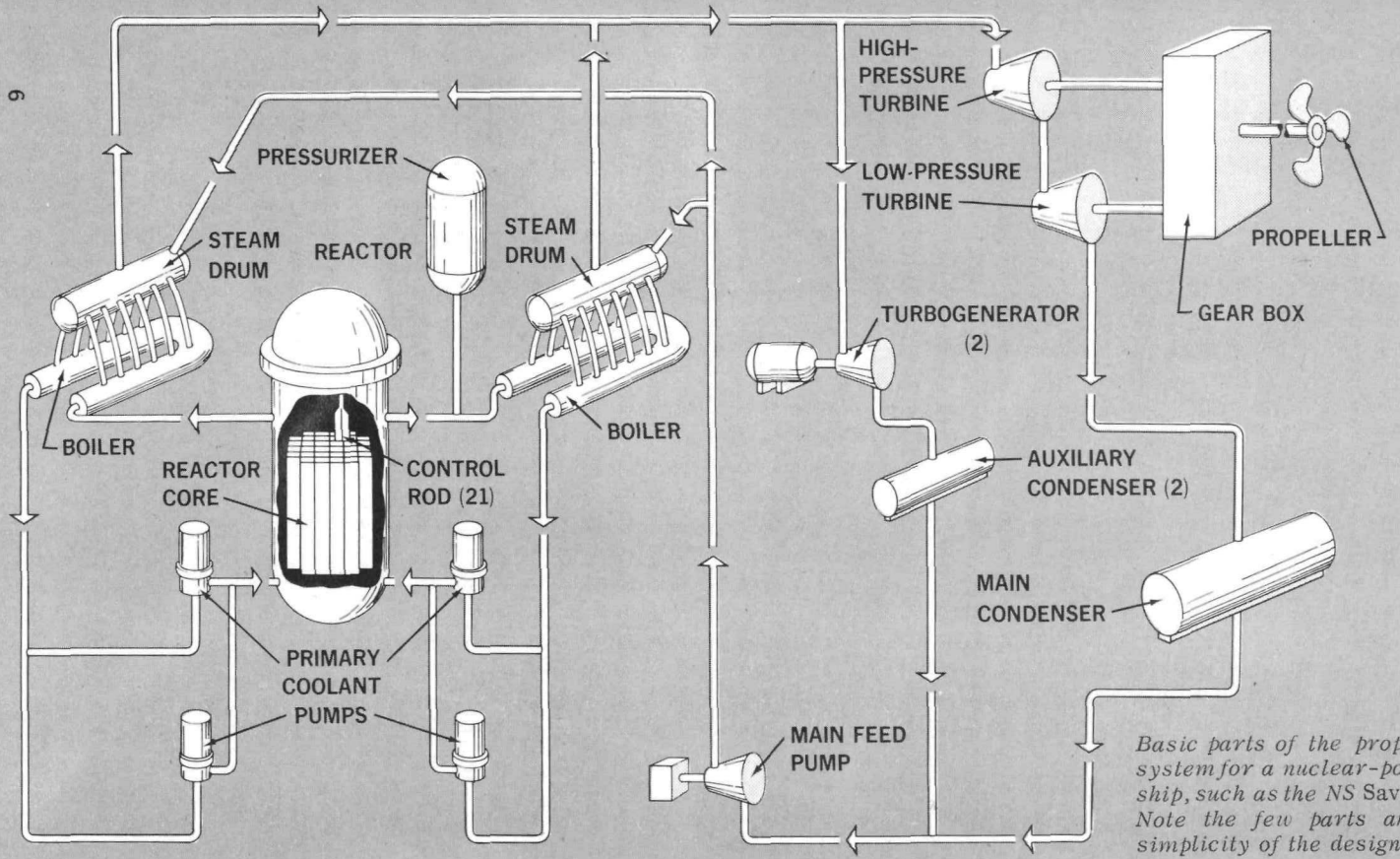
Some Dissent

This listing of the advantages expected of nuclear energy in the merchant fleet is frankly optimistic. Not everyone shares this optimism. Some naval architects, shipbuilders, and shipowners are not yet convinced; others actively doubt the reality or degree of these advantages. Still others believe the costs and troubles of building and operating nuclear merchantmen overbalance possible benefits. Today shipbuilders and shipowners know precisely the costs, advantages, and disadvantages of conventional ships; the costs, advantages, and disadvantages of nuclear shipping are still conjectural and will remain so until enough nuclear ships are at sea to provide adequate information.

Taking the Atom to Sea

On land a nuclear power station faces few dangers from Nature. Putting a nuclear power plant into a ship and sending it to sea exposes it to a vastly different, sometimes hostile environment. A ship is a moving, vibrating platform. A nuclear ship must face all the hazards of the sea and would be of little use if it had to run for harbor at the first signs of storm. A ship must have reliable, safe power whatever the weather. Despite the rolling and pitching that a ship battling a storm encounters, its engines must faithfully provide power for steering and moving ahead. Even in calm seas a nuclear ship faces the ancient maritime hazards of grounding, collision, and sinking. Additionally, a nuclear ship must be so designed and built that passengers and crew are protected from uncontrolled release of radiation or radioactive materials if an accident should occur.

Since a nuclear power plant generates radiation and radioactive materials, a nuclear ship's passengers and crew and the people living and working near harbors and along nearby coasts also must be protected. Naval architects and nuclear engineers know these hazards and can design



Basic parts of the propulsion system for a nuclear-powered ship, such as the NS Savannah. *Note the few parts and the simplicity of the design.*

ships and power plants to exceed all safety requirements of maritime nations and of the International Atomic Energy Agency.

How Nuclear Energy Is Produced

A steam engine or an internal combustion engine uses heat from burning fuels to generate mechanical energy. A nuclear engine uses heat from the conversion of matter into energy to produce mechanical energy. But the firebox and boiler of a steamship are fundamentally different from a nuclear reactor. A conventional marine propulsion system includes machinery to combine oxygen from the air with the carbon and hydrogen in oil. The fuel is burned within a firebox to produce hot gases that pass through a boiler and give up some heat to produce steam. The fuel in the firebox must be continuously replenished. Large fans force great volumes of air into the firebox to supply the oxygen for combustion. Air and exhaust gas ducts take up much space. Fuel oil is stored in tanks and is pumped to the firebox. In addition to producing useful energy, the engines discharge noxious gases, unconsumed fuel, and soot to the air.

In comparison, a nuclear reactor is not spectacular. There are no jets of burning fuel, no thundering blasts of air and hot gases, and no swirling smoke, soot, or fumes. Instead, within a typical reactor, where it cannot be seen, there is a collection, or core, of plates, rods, or tubes, that becomes hot because of fissioning atoms of uranium. Circulating water or some other coolant quietly takes the heat from the core to a heat exchanger where steam is generated. (In one type of reactor, heat from the core boils the water directly.)

A reactor is a device to start, control, and confine the process of converting matter into energy. This process involves the splitting apart, or fissioning, of atoms of uranium isotope 235, with the release of heat and radiation and the creation of radioactive debris, or fission products.* The nuclear fuel is the most important part of a reactor. Con-

*For further information on nuclear fission, see *Our Atomic World,* a companion booklet in this series.

trol rods govern the availability of neutrons to sustain a chain reaction; the moderator slows the high-speed neutrons resulting from fission to speeds most likely to produce new fissions; the coolant carries away the heat from the fuel; a vessel contains the fuel, controls, and moderator; shielding protects persons from radiation; and usually an outer container confines any radioactive materials that might be released in the event of an accident or malfunction.

Engineers have thought of many ways to combine these parts; from these combinations have emerged a few reactor concepts that appear promising for maritime use.*

THE NS *SAVANNAH*

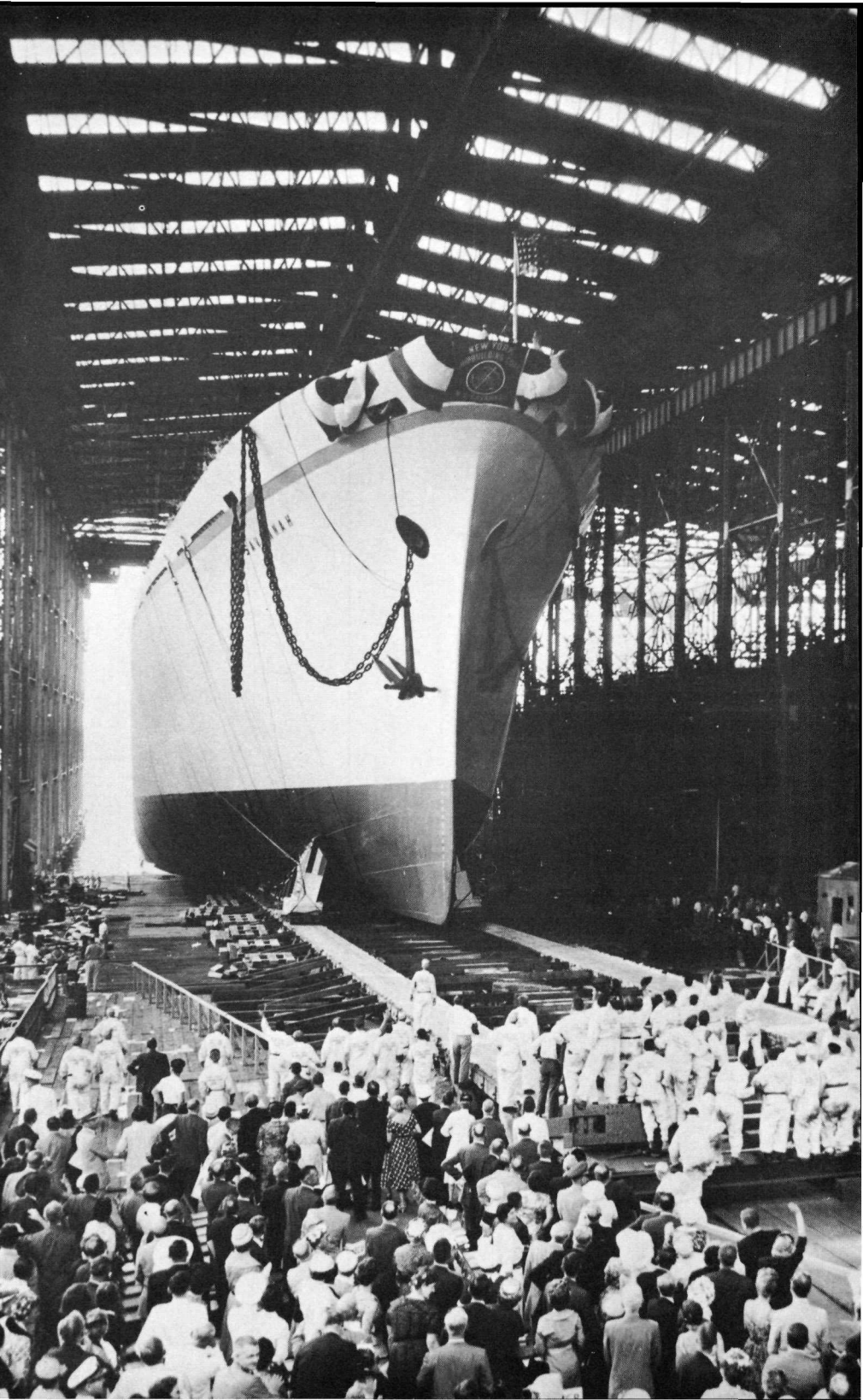
Origin and History

Even during the World War II rush to make the atomic bomb, scientists and engineers found time to think about using nuclear energy at sea. This interest caught the imagination of enough men to lead to the launching of the nuclear submarine *Nautilus* in 1954 and to today's other nuclear Navy ships. Naval architects and engineers and reactor engineers also were interested in the potential of nuclear energy for commercial shipping. By 1955 so many men had dreamed, planned, and worked for maritime nuclear power that President Eisenhower could recommend building a merchant ship powered by nuclear energy. Congress agreed, and authorized development and construction of such a vessel, and on October 15, 1956, President Eisenhower directed the Department of Commerce and the Atomic Energy Commission (AEC) to go ahead.

The two agencies set up a joint group that quickly enlisted the assistance of private industry. George G. Sharp, Inc., of New York, a noted marine architectural firm, designed the

The NS Savannah *sliding down the ways on July 21, 1959, at launching ceremonies at Camden, New Jersey.*

*For more information on nuclear reactors, see *Nuclear Reactors*, a companion booklet in this series.

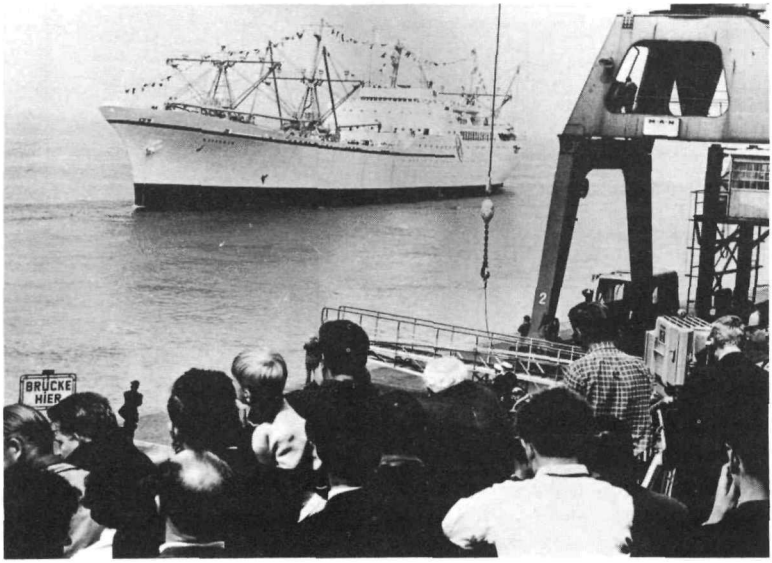


ship. The New York Shipbuilding Corp. of Camden, New Jersey, built her, and the Babcock & Wilcox Co. designed and built the nuclear reactor and furnished the propulsion machinery. Later the Maritime Administration (part of the Department of Commerce) contracted with a shipping company, the States Marine Lines of New York, to operate the new ship as part of its fleet.

From the beginning the new ship was thought of as part of the United States' program for demonstrating peaceful uses of atomic energy. She was not intended to prove or disprove the economics of maritime nuclear propulsion. Rather, as a floating engineering laboratory, she was to help identify, define, and solve problems of design, operation, and manning that would benefit those building future nuclear merchantmen.

The new ship took form quickly. On National Maritime Day, May 22, 1958, her keel was laid, and a little more than a year later on July 21, 1959, Mrs. Eisenhower launched the new ship, christening her the NS *Savannah* as a successor to the early *Savannah.* Then long and intensive testing of the nuclear power plant began. Since no prototype had been built for her reactor, all changes in design and all retesting to incorporate last-minute improvements had to be done aboard the ship as she floated in her dock.

Keeping pace with the installation of the reactor, the Atomic Energy Commission held public hearings on the safety of the reactor and in July 1961 gave approval to load and start it. Testing of all reactor systems was finished in October, and on December 21, 1961, a low-power chain reaction was started. Thereafter nuclear tests continued until the reactor had been brought to 10% of its designed power. The NS *Savannah* then moved to Yorktown, Virginia, for full-power testing and sea trials. Her tests were successful, and she was delivered to the States Marine Lines on May 1, 1962. A few months later the NS *Savannah* departed on her first tour, visiting eleven American ports. She passed through the Panama Canal, visited Hawaii, and stopped at Seattle, where she was a featured attraction of the 1962 World's Fair. This voyage ended in Galveston, Texas, where the Maritime Administration had established a nuclear service facility. During the winter of 1962–63,

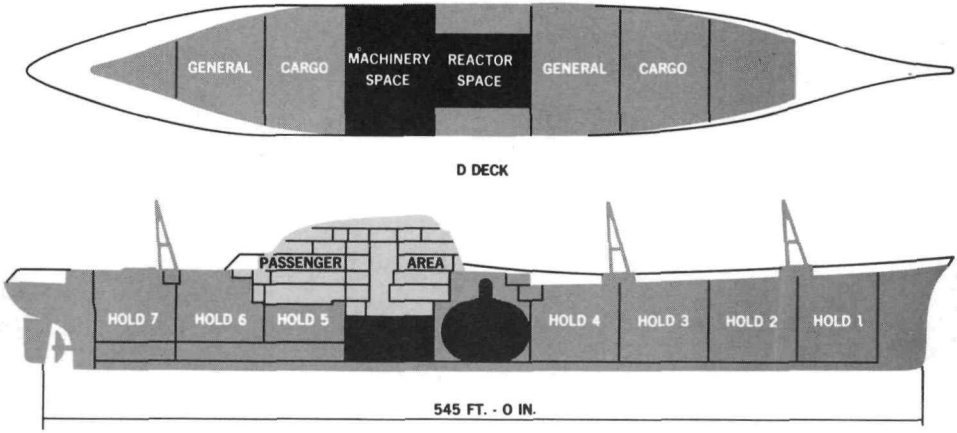


The Savannah *arriving at Bremerhaven, Germany, her first European port of call, after her first Atlantic crossing. She visited 11 other countries during this journey.*

inspections and planned modifications were made, and preparations were begun for visits to new ports at home and in Europe.

But these visits had to be postponed. Early in 1963 the ship's operating engineers went on strike in a complicated labor dispute. When the issues could not be resolved by normal collective bargaining, the Maritime Administration ended its arrangement with the States Marine Lines and invited new proposals for operation of the NS *Savannah.* In July 1963 the American Export Isbrandtsen Line of New York was chosen. A new contract was negotiated, and a new crew was recruited and trained.

The *Savannah* resumed her voyages in 1964–65, visiting nearly a score of domestic ports and making 10 crossings of the Atlantic to call at more than a dozen leading ports in Europe. All told, the ship steamed 89,818 miles on nuclear power in sea trials and demonstration visits, stopped at 46 ports and received more than 1,389,000 visitors on board. In making these trips she burned only 35 *pounds* of uranium-235!



Plan of a nuclear-powered merchant ship showing passenger areas and cargo space.

The terms of the new operating contract represented an important step toward general maritime use of nuclear power. Under it, the *Savannah* was operated at similar manning levels and at the same wage rates that prevailed on other American Export Isbrandtsen Line ships.

In August 1965 the *Savannah* was placed in commercial service by a subsidiary of the line. She was assigned to carry cargo only on the company's North Atlantic and Mediterranean runs.

Description

The NS *Savannah* is a beautiful ship, having a graceful clipper bow, a streamlined superstructure, and a cruiser stern. Her most distinguishable feature is the absence of a funnel for smoke and fumes. She is 595 feet long (about as long as two football fields), 78 feet wide, and draws $29\frac{1}{2}$ feet of water. She carries a crew of 110 and 9300 tons of dry cargo, equivalent to the load in 4 freight trains of 80 cars each. Fully loaded, she displaces 20,000 tons. Like many modern cargo ships, she carries passengers and has cabins for 60. Her cruising speed is about 21 knots, or almost 24 statute miles per hour. Her turbines develop 22,000 horsepower. Passenger accommodations, cargo-handling equipment, communications, and navigation equipment illustrate the best in American merchant ship design.

The *Savannah* has six decks, with cargo platforms at lower levels. A promenade deck extends over the main passenger deck for about one-third the ship's length. Above this are a shorter boat deck and a navigating-bridge deck. On a second passenger deck are the galley and dining room. Crew's quarters and a viewing gallery overlooking the reactor control room are nearby.

Comparison with Conventional Ships

Since the *Savannah* was designed as a conventional ship in which a nuclear reactor replaced the boiler, she is quite similar in size to the Mariner type freighter. This class vessel sails at 20 knots and has a large freight capacity adaptable to many different dry cargoes. The *Savannah* is slightly longer and wider than a Mariner. Fully loaded with fuel and cargo, both ships weigh almost the same, but 2600 tons of a Mariner's capacity is reserved for fuel oil, an item not needed on the *Savannah*.

The American Challenger, *pictured at sea, is an example of a modern, high-speed conventional merchant vessel.*

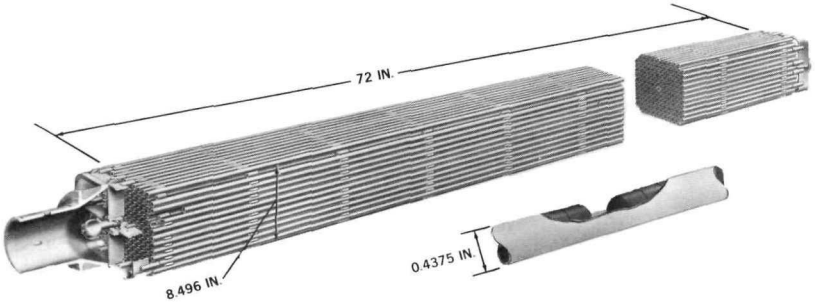
POWER FOR THE NS *SAVANNAH*

The *Savannah's* nuclear power plant is simple in principle. Uranium, artificially enriched to ensure readily fissionable atoms, is contained in fuel elements within the core. When rods are withdrawn, a chain reaction starts in the fuel. Fissioning uranium quickly heats surrounding water to high temperatures, over twice the normal boiling point. A pressurizer keeps the water under enough pressure to prevent boiling, which would cause unstable operation. The very hot water is pumped through the boilers, where it gives up part of its heat to make steam, and then returns to the reactor to pick up more heat. Steam from the boilers flows to the main turbines, which drive the turbogenerators of the main propulsion system. Unused steam returns to the boilers via condensers, which convert it to water. At full power the *Savannah's* reactor core gives off heat energy equivalent to 80 megawatts of electricity.

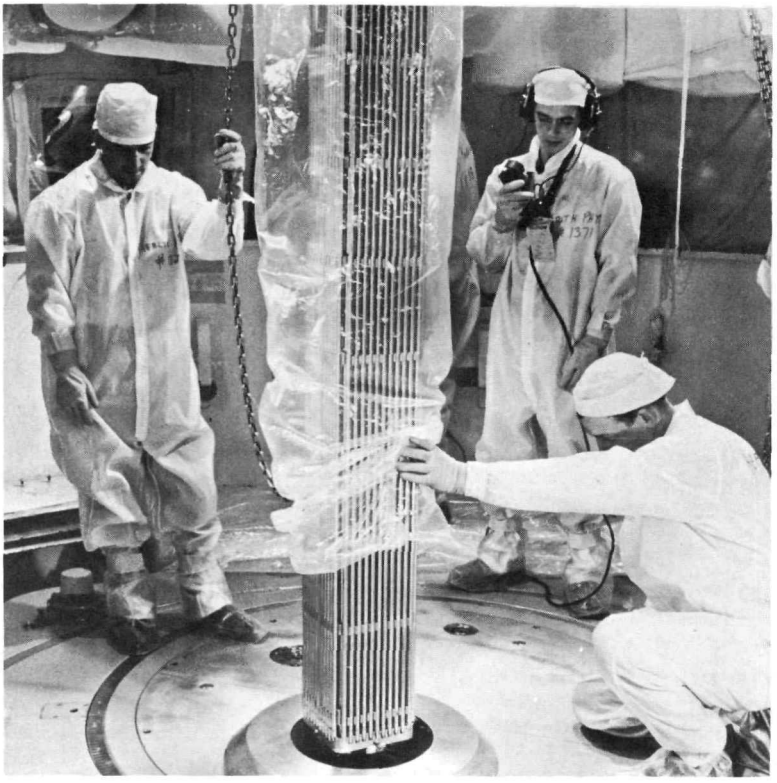
Fuel

Fuel for the *Savannah* is uranium enriched to an average value of 4.4%. This means it has more uranium-235 than the 0.7% in natural uranium. This slight enrichment simplified design of the fuel elements and the reactor by permitting use of structural materials that are resistant to corrosion and radiation. The uranium, in the form of uranium dioxide, is compressed into pellets. These are slipped into tubes of stainless steel called fuel pins. Uranium dioxide was chosen because it does not react chemically with water, has a high melting point, and can hold its shape at the high-temperature and high-radiation levels within a reactor. The fuel pins are assembled into 32 fuel elements, each containing 164 pins, for a total of 5248. These fuel elements are designed to the standards set for land-based nuclear power plants and in addition are made to withstand the shock and vibration from motion of the ship.

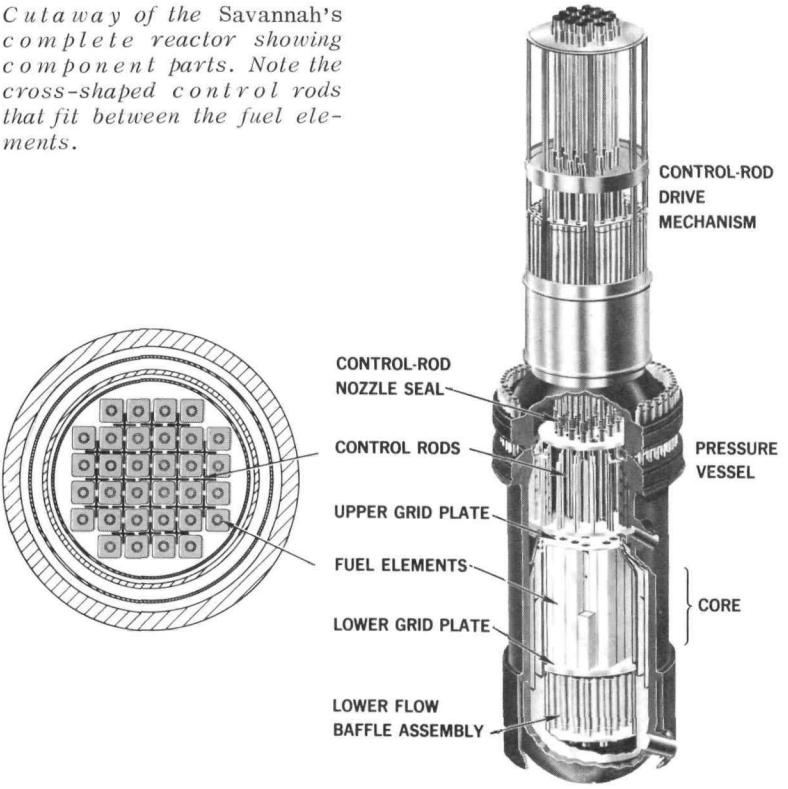
The *Savannah's* first core is designed to last about 3 years, assuming she is at sea 60% of the time. It contains 17,000 pounds of uranium, of which 668 pounds is uranium-235. During its useful life, about 130 pounds of uranium-235



Fuel elements for the world's first nuclear merchant ship. Bundles of clean, uranium-filled tubes are lowered into the reactor aboard the Savannah *(below), after being slipped from their protective polyethylene covering. Drawing (above) shows details of the tubes, which provide the same energy as great quantities of oil.*



Cutaway of the Savannah's *complete reactor showing component parts. Note the cross-shaped control rods that fit between the fuel elements.*



will be fissioned within the core. With one loading she can cruise 300,000 nautical miles at a speed of 21 knots, increasing to 23 knots when necessary. This is equivalent to 12 trips around the earth at the equator. On such a journey, in which any conventional ship of the same size would consume four to five times its own weight in fuel, the *Savannah* will have used a quantity of nuclear fuel weighing less than one of her passengers!

Control Rods

Interspaced among the fuel elements within the core are 21 control rods. These contain neutron-absorbing boron. Depending on the position of the rods within the core, a nuclear chain reaction can be started, maintained, or shut down. Neutron detectors actuate electronic circuits that

govern the drive mechanism for the control rods. These circuits can maintain the chain reaction automatically at a desired level, be it full power for top speed, or just enough power to run the ship's generating system.

Pressure Vessel

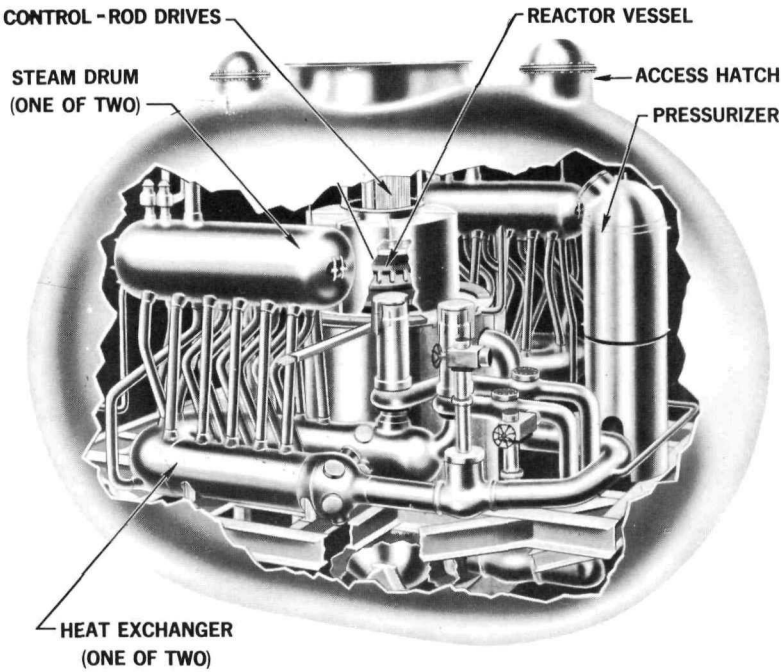
A massive steel vessel contains the *Savannah's* nuclear core. It is 27 feet high and has an inner diameter of more than 8 feet. Its walls are 6.5 inches thick, with the inner surfaces clad with stainless steel to prevent corrosion. The upper head of this pressure vessel is removable to permit loading and unloading the core. Forging and machining this pressure vessel was a work of the highest industrial craftsmanship.

Steam Generation

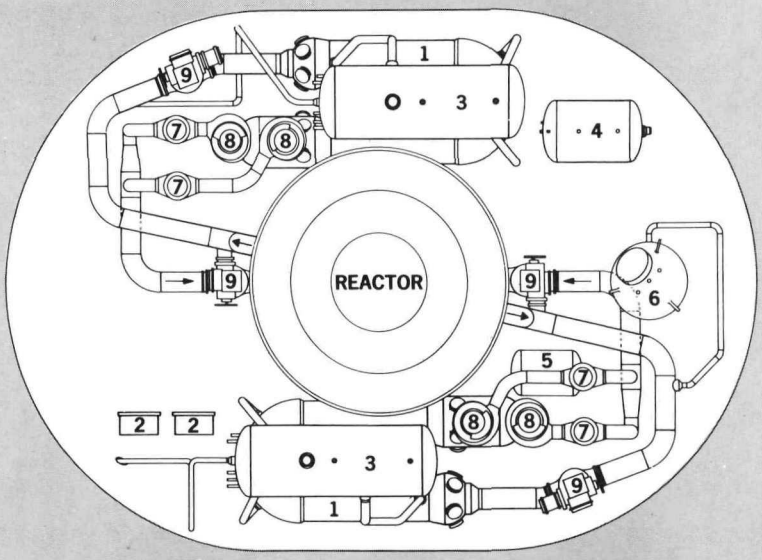
Hot water from the reactor flows to a boiler where some of its heat is given up to make steam. The water then returns to the reactor to pick up more heat and repeat the journey. This design isolates the turbine and engine room from any radioactive materials in the reactor, for there is no open path from the hot-water loop to the steam loop. Two heat exchangers with independent pumps were installed to assure reliable cooling of the reactor core. When the *Savannah's* captain calls for full power, heat energy flows from her reactor at the rate of 80 megawatts per hour and is carried to the boilers to generate 265,850 pounds of steam per hour at pressures from 445 to 715 pounds per square inch.

Containment Vessel

Land-based power reactors and the parts of their systems that may contain radioactive materials are enclosed in a containment vessel. The *Savannah* has one too. In it are the reactor core in its pressure vessel, the water pumps, the boiler, the steam drums, and the pressurizer. The drawing shows how compactly these parts are fitted into the containment vessel. It is a large structure, 50.5 feet



The Savannah's *steam-generating equipment. Note how compactly the reactor, pumps, and steam generators fit within the containment vessel. Future nuclear ships may take advantage of engineering advances that will permit smaller components and savings in weight and volume for machinery.*



1. HEAT EXCHANGER
2. LETDOWN COOLERS
3. STEAM DRUM
4. CONDENSING TANK
5. CONTAINMENT DRAIN TANK
6. PRESSURIZER
7. CHECK VALVE
8. PUMP
9. GATE VALVE

long and 35 feet in diameter, about the size of four living rooms put together. Its walls are carbon steel up to $2\frac{3}{8}$ inches thick and are designed to contain an internal pressure of 186 pounds per square inch. This is more than would result from a complete rupture of the reactor's cooling system.

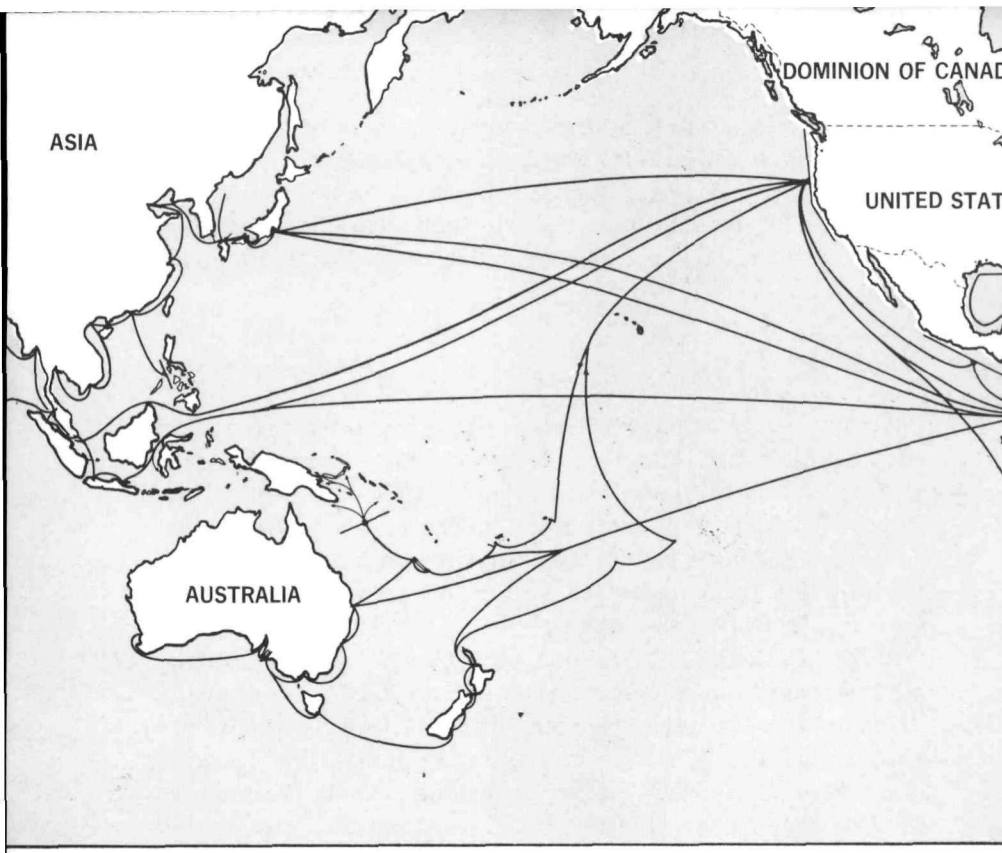
Shielding

When in operation, a nuclear core gives off neutrons and gamma rays that could cause injury unless properly confined. Gamma radiation also is given off by the radioactive materials that result from fission. The function of shielding is to confine these radiations to permit routine operation of the ship and to protect passengers and crew. The *Savannah* has two distinct sets of shields. The first is built around the reactor vessel. It reduces the escape of neutrons and gamma radiation sufficiently to permit the crew to enter the containment vessel for short times after the reactor is shut down. The secondary shielding is outside the containment vessel. It would serve to reduce personnel exposure to radiation should a reactor accident release radioactive materials within the containment vessel.

The primary shield consists of a layer of water 33 inches thick, supplemented by a layer of lead. The secondary shielding is a combination of lead and polyethylene around the upper part of the containment vessel and concrete around the lower portion.

Radioactive Wastes

Any nuclear power plant creates radioactive wastes. Tools and clothing, used resins from water purifiers, wiping cloths, and other items may become contaminated with radioactivity. The standard practice is to collect most such wastes for disposal, usually by burial on land. Radioactive liquids and gases are created during reactor operation. Some wastes are so slightly radioactive that they can be mixed with air or water and be discharged to the air or sea. The *Savannah* is equipped to collect and store wastes, or to release them in diluted form.



World trade routes. Free-flowing foreign trade works to the

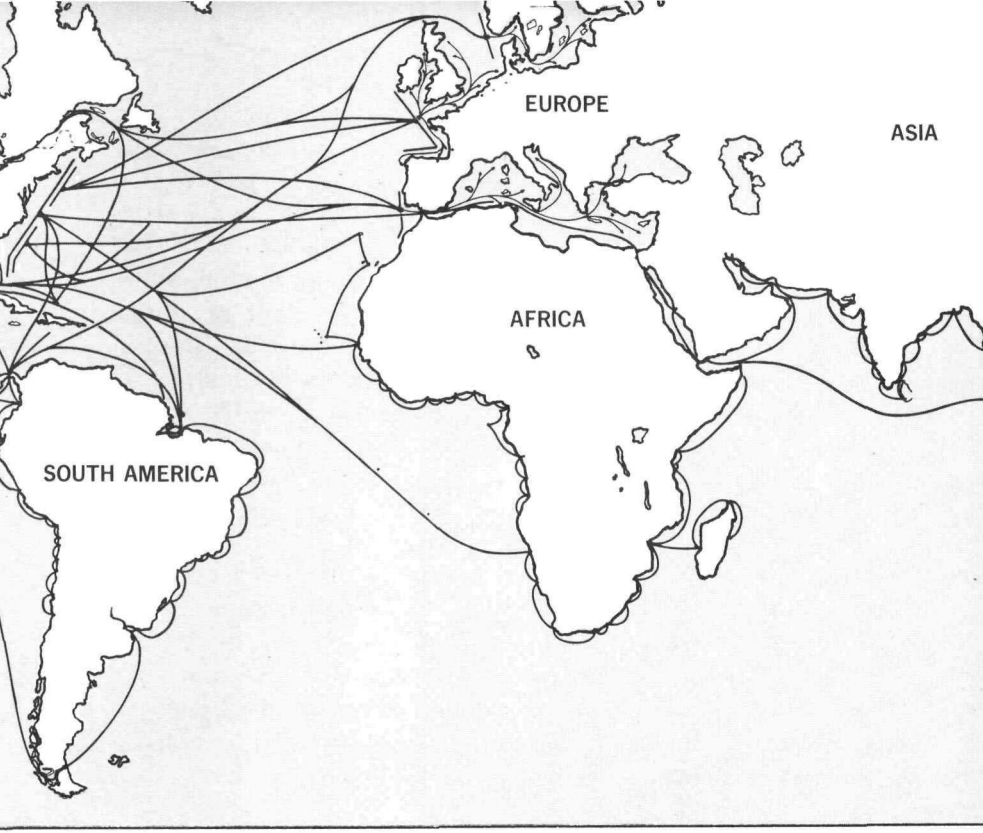
Emergency Power

Because practical experience with maritime use of nuclear power is still limited, the *Savannah* is equipped with auxiliary electric power to bring her back to port should there be difficulty with her reactor. Two diesel–electric generators can furnish electricity to turn her propeller, supply the ship's other electrical needs, and operate a cooling pump for the reactor.

FOREIGN TRADE AND FISSION

Exports, Imports, and Economic Health

Stop for a moment and ask yourself what would happen if the merchant fleets of the world were suddenly to vanish.



fit of all nations. Nuclear power promises to open up new markets.

How would raw materials, fuel, food, medicines, publications, and manufactured products move from one continent to another? No nation is completely self-sufficient; all find advantage in foreign trade. For example, 15 of the materials used in making a telephone in the United States must be imported. The industrialization now beginning in developing nations of Africa, Asia, and South America foretells increasing foreign trade, to be carried by the merchant marine.

Spend a minute looking at the map above. Note how many trade routes cross great stretches of open water. The quicker and more reliably these crossings can be made, the better the prospects for healthy foreign trade.

Consider the economic importance of foreign trade. Of our 1963 Gross National Product of $633 billion, import and export trade accounted for about $40 billion. Foreign trade

involved the movement of 385 million tons of exports from our ports and 227 million tons of imports, making the United States the largest trading country of the world. The value of our oceanborne foreign commerce is expected to double by 1985. Some bulk commodities in export trade, such as coal, scrap iron and steel, grains, and cotton, should increase by 65% through 1975, and imports of certain minerals, sugar, and petroleum products are expected to increase by 47%.

Many major cities of the United States are seaports, even though some of them are far from oceans. Each ton of general cargo moving through a port leaves an estimated $16 to $20 in the community as the income from handling charges. Handling of all waterborne cargo, domestic and foreign, through United States ports in 1963 amounted to about $8 billion. The port of Cleveland, Ohio, for example, benefited in 1963 by over $50 million from handling waterborne commerce. In terms of jobs, nearly 6 out of every 100 workers in the United States depend upon exports for their employment. Even in a landlocked state like Arkansas, for example, 14 out of every 100 workers hold jobs dependent on exports.

The American Merchant Marine

Sailing ships helped to knit together the original American colonies and provided communication and transportation favoring the new nation's growth. Since our nation began, the merchant fleet also has supported our navy and our armies in wartime.

The early nineteenth century brought peak activity and success to the American merchant marine. The famous clipper ships of that glorious period made their long, fast voyages from New England and East Coast ports to California, India, China, and throughout the Pacific Ocean.

But this maritime prosperity did not last. The discovery of gold, the lure of free land, and preoccupation with industrialization turned the attention of the nation inland. Early Congressional encouragement faded, and the merchant fleet fell behind foreign fleets that did receive assistance from their governments.

The demands of World War I again brought expansion, as shipyards raced to build ships to supply our troops over-

seas, but after 1918 the fleet again headed into a slump. World War II once more stimulated a great increase in shipbuilding. Yet with victory the merchant fleet again declined. In 1946 American ships carried about 70% of our foreign trade. In 1964 they carried only 8.5%.

The 1960s find American shipping still in the doldrums. Worse still, the war-years' ships are aging rapidly. In another year or two, about 91% of the merchant fleet will be 20 or more years old. Although these ships are seaworthy, their slower speeds, higher operating costs, and slower cargo-handling facilities make competition with modern foreign ships increasingly unfavorable. As American standards of living rise, labor costs for crews of American ships also go up relative to those of foreign lines. This makes shipping in U. S. vessels more costly.

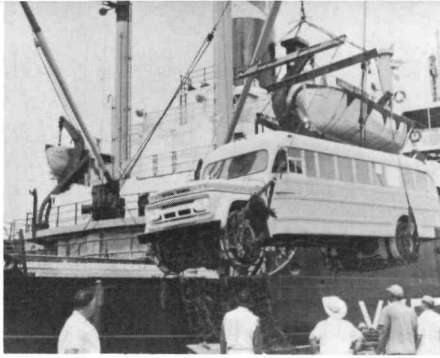
Is there any hope for the American merchant marine? Optimistic naval architects, shipbuilders, and shipping companies look to radically new designs, to automation, and to nuclear power to help it regain the dominant place once secured by our clipper ships. Because so many ships in the fleet are due to be replaced at about the same time, any technological improvements that are not incorporated soon may have to wait perhaps another 10 years for widespread use. During the next few years, many decisions that will affect our merchant fleet will be made. One such decision is when and how to use nuclear power.

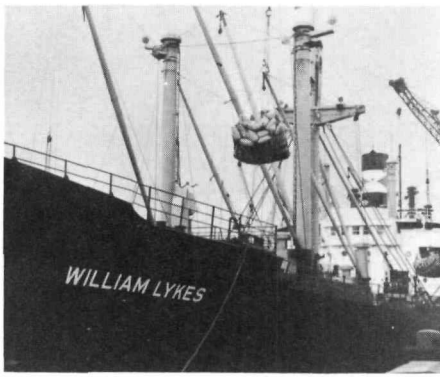
Foreign Trade

The main benefit expected from nuclear power in maritime use is sustained long-range high-speed operation. Fuel consumption for conventional ships increases very rapidly as speeds increase. To operate at 30 knots, proponents of nuclear power say, conventional ships will need such large fuel tanks that the capacity remaining for cargo will drop below the point of profitable return. Nuclear ships, on the other hand, require little fuel storage space. Under the AEC maritime reactor development program, compact lightweight reactors have been developed. High-speed ships using such plants will cost less to operate than a conventional ship in some dry-cargo services. Moreover, the eco-

nomics of nuclear power probably will improve rapidly with use.

George G. Sharp, Inc., designer of the *Savannah,* predicts that a fleet of fast nuclear freighters could create a new kind of marine transportation. The company, in a report required under a contract to the Maritime Administration, estimated that a fleet of 30-knot freighters large enough to maintain express service on a North Atlantic trade route would cost slightly less than conventional counterparts; for longer routes in the Pacific, Sharp believes nuclear ships would be cheaper. A jump in speed to 30 knots would give U. S. shippers a large competitive advantage and could be expected to create new business as well as capture existing trade.





Foreign trade is a two-way street. A bus (top) is loaded in an American port for shipment to Turkey. Asbestos (bottom) is loaded on an American vessel in Capetown, South Africa, for transport to the United States.

"There exists strong evidence that high speed of itself generates cargo," said the Sharp report, and also "... the cargo which seeks faster ships is generally higher-rate cargo."

Consumer products, including newspapers, magazines, cigarettes, electrical equipment, instruments, television parts, medical supplies, drugs, air conditioners, and refrigerators are likely products to be shipped in express service. So too are machinery, agricultural implements, tractors, road-building equipment, automobiles, engines, and business machines.

If nuclear power has all these advantages, why haven't more ships been constructed? First, the *Savannah's* plant was not intended to be economically competitive, and the

compact, lightweight reactors, which are expected to be competitive with conventional power, are only now becoming available. Secondly, the *Savannah's* mission in developing port access, safety requirements, and licensing and insurance considerations and in achieving public acceptance of maritime nuclear power has only begun, and must precede the commercial applications. Finally, the operators must have an opportunity to review the possibilities after they have been acceptably demonstrated.

The signs appear encouraging. First of all, the visits of the *Savannah* to foreign ports have been well received and port-clearance procedures have been arranged. Moreover, several shipping companies in the United States are studying maritime nuclear power, and two have recently made proposals for a joint private industry–government undertaking to bring it into early use.

In October 1964 the American Export Isbrandtsen Line, operator of the NS *Savannah*, told the AEC and the Maritime Administration that it was ready to commit itself to an immediate program of nuclear vessel construction for service between the East Coast of the United States and the Orient. The proposal called for constructing a fleet of four 30-knot express freighters with costs to be shared equally by the company and the government under the Merchant Marine Act of 1936. To provide the same volume of service with slower conventional ships would require six vessels of the Mariner class.

In February 1965 the American-Hawaiian Steamship Company stated its interest in nuclear power for large new 900-foot ships for use in intercoastal trade.

Congress also is interested, as evidenced by a bill introduced in January 1965 to authorize government aid in developing, constructing, and operating privately owned nuclear-powered merchant ships.

SPECIAL CONSIDERATIONS

Costs alone will not decide between conventional and nuclear power for maritime service. The technical advantages of nuclear power may be worth more than any added

cost. Other factors that will affect decisions include safety, servicing, port acceptance, training, and insurance.

Safety

Sailing the seas has always been hazardous. Quite understandably, mariners and shipowners, the public and governments, all wish to see whether nuclear power will add any new hazards. One primary function of the *Savannah* is to demonstrate the practical safety of this new source of power.

The *Savannah* is designed to be safe. But the Atomic Energy Commission was not satisfied to rely solely upon the skill of her designers. The design and construction and the testing and operation of her power plant have been scrutinized in exceptionally fine detail by the Commission. Much of this examination was conducted in hearings that members of the public could and did attend. Public understanding of the safety of nuclear power at sea is a prerequisite to its fullest use. It is intended that the *Savannah* will provide a convincing, visible demonstration of safe operation that will assure it and other nuclear ships a friendly welcome in ports throughout the world.

Servicing

Just as automobiles, aircraft, and conventional steamships need servicing and maintenance, so do nuclear ships. One assignment of the *Savannah* is to show what servicing and maintenance will be needed.

The Maritime Administration has established permanent facilities for servicing commercial nuclear ships at the Todd Shipyards Corp., Galveston, Texas. In addition to the usual pier and shipyard cranes, the facilities include laboratories and a building with several special rooms. There is a "clean room," which is kept extraordinarily free from dirt and dust. Here parts of the reactor can be serviced without introducing foreign matter into the nuclear system. There is a room equipped to clean equipment and items that become contaminated with radioactive materials. One machine shop is capable of working on radioactive equipment.

Also the facility has refueling equipment, a deep pit in which to store used cores, a laboratory, and a barge equipped to dispose of radioactive wastes and to provide other essential services.

Facilities alone cannot maintain a nuclear ship. It takes men, too. The Babcock & Wilcox Co. and the Todd Shipyards Corp. have recruited a staff of engineers and technicians that is capable of making the repairs and servicing commercial nuclear merchant ships. Although this staff is now maintained at government expense, it is thought that greater use of nuclear power will provide it with private work and permit gradual withdrawal of government support.

Port Acceptance

Another task of the *Savannah* is to give port officials throughout the world a personal awareness of maritime nuclear power. Present rules and regulations were not drawn up to accommodate nuclear merchant ships. These regulations must be revised if nuclear ship visits become routine. The economic pressure to load and unload nuclear ships quickly and to keep them at sea, where their earning capacity will be the greatest, means that shipowners will demand clearly defined regulations that will make short stays in port possible.

Another aspect of port acceptance is good public relations. Maritime nuclear power would not flourish if nuclear merchantmen were forced to enter ports under cover of sovereign immunity or secrecy, nor if central governments forced unwilling port officials to receive them as unwelcome visitors.

For these reasons, the Maritime Administration has made careful preparations to assure a friendly welcome for the NS *Savannah* in ports at home and overseas. International agreements must be negotiated to extend to host countries the same financial protection in the event of a nuclear accident that Congress has established for domestic ports. Advance agents from the American Export Isbrandtsen Line and the U. S. Government visit each port of call for the *Savannah*. A specific written plan and analysis of each port is submitted for review and approval to

The SS United States, *leader of the United States' merchant fleet passes the skyscrapers of New York City outward bound for Europe.*

the host government, to the Coast Guard, and to the Atomic Energy Commission. Before the *Savannah* can visit a port, this plan must be agreed upon by everyone concerned, including local officials.

A second round of port acceptance activities opens when the *Savannah* begins a visit. This is to bring to the citizens of the port city a full understanding of the nature and potential benefits of maritime nuclear power. The *Savannah* solicits and carries commercial cargo, which is loaded and unloaded by stevedores of the ports in normal fashion. Thousands of visitors stream through her daily while she is in port, and public and professional groups meet aboard her at night. Movies, exhibits, brochures, pamphlets, souvenirs, and photographs are used to arouse interest in her and what she heralds for the future.

The Savannah *receiving a noisy welcome from tugboats and a fireboat as she entered New York harbor for the first time.*

Training

A nuclear ship requires special training for crews and officers. The *Savannah* shows what kind of training is needed and how it can be provided, as well as serving as a training facility. If training requirements are too onerous, nuclear ships will be slow to gain support; on the other hand, crews and officers must be qualified to make the best and safest use of nuclear power. The Maritime Administration has directed the Merchant Marine Academy at Kings Point, New York, to offer courses in reactor engineering, reactor safety, reactor operation, instrumentation and electrical engineering, health physics, and kindred subjects. After completing this academic training in a busy five months, engineering officers receive three additional months of

A professor of nuclear physics explains the use of a subcritical reactor in experiments in the Nuclear Engineering Laboratory, U. S. Merchant Marine Academy, Kings Point, New York. With this and other teaching devices, future merchant marine officers become acquainted with nuclear science.

practical experience on the *Savannah* before they take AEC examinations for reactor operators' licenses.

It is expected that a steady flow of graduate officers will take this training until the undergraduate curriculum is altered and the Academy begins to produce graduates qualified in nuclear engineering as part of its regular instruction.

Insurance

Shippers were among the first to use insurance to protect themselves from losses. An invisible but very real web of insurance covers every voyage of all merchant ships. For insurance underwriters to furnish financial protection against accident, they must know how often various kinds of accidents occur. A nuclear vessel in private ownership will need insurance against all the same kinds of accidents that

might occur in the operation of any ship, plus special coverage to deal with nuclear accidents.

Nuclear energy is so new, however, that statistical information about it is still nonexistent. Until national legislation and international agreement define and limit the nuclear accident liability of nuclear-ship owners and operators, as has been done in the cases of conventional ships and aircraft, the underwriters will have no basis on which to establish limits for this special insurance. In 1961 an international conference in Brussels recommended a liability limit of $100 million for accidents involving release of radioactive materials, but this has yet to be ratified by the principal nuclear nations.

In the meanwhile, the *Savannah* is protected financially by an act of Congress by which the U. S. Government assumes limited liability in the event of nuclear accidents. Operating experience with the *Savannah* will provide a basis on which the frequency of claims for damage from nuclear accidents can be predicted, so that underwriters can extend their traditional insurance to nuclear shipping. Or it may be that the governments owning future nuclear ships may provide such insurance directly.

WORLD NUCLEAR SHIP DEVELOPMENT

With the NS *Savannah* a reality, shipbuilders and shipowners in many countries are giving serious thought to nuclear power. To date, however, the only nations to build nuclear-powered ships for civilian purposes are the United States and the Soviet Union.

Soviet Union

Much of the Soviet Union lies in or near Arctic regions. As explained by A. P. Alexandrov at the Second United Nations International Conference on the Peaceful Uses of Atomic Energy in 1958, the economic development of the Soviet Union's northern regions makes the use of powerful icebreakers most desirable to clear the way for convoys along a northern sea route and to extend this route deeper into the Arctic. Ice breaking is heavy work. Conventional

The Russian icebreaker Lenin *in the Barents Sea. Nuclear power is a practical solution to the difficulty of all-year navigation in the polar regions.*

icebreakers need frequent refueling and therefore cannot navigate the whole Arctic Basin. Fuel limitations restrict them to a narrow coastal strip where ice conditions are generally severe. To overcome these adversities, the Soviet Government designed and built a nuclear-powered icebreaker, the *Lenin,* which joined the Soviet Arctic fleet in December 1959. According to Soviet representatives at the Third United Nations International Conference on the Peaceful Uses of Atomic Energy in 1964, by the end of 1963 the *Lenin* had sailed about 60,000 miles, 40,000 of which were in ice. Two sister ships are now planned for 1971. If atomic icebreakers can open the Arctic Ocean for shipping throughout the year, convoys of ships then could sail between Murmansk and Vladivostok across the top of Siberia, a distance of 5805 miles. By way of the Suez Canal, it is almost 13,000 miles—more than twice as far—between those ports. The economic advantages are obvious.

Soviet interest is also turning to other merchant uses. In March 1964 it was announced that the USSR State Committee on Shipbuilding was anticipating a future time when nuclear-powered tankers would be operating at 25 knots.

United Kingdom

British shipbuilders and ship designers are well aware of the potential benefits of maritime nuclear power. Britain's merchant fleet sails many of the world's longer routes. The U. K. Atomic Energy Authority, which has the responsibility for developing a suitable nuclear power plant, is considering several different types of nuclear reactors. It is expected one soon will be chosen to meet the United Kingdom's technical and economic requirements. Several types of ships have been proposed, including a tanker, a dry-cargo ship, a refrigerated-cargo ship, and a fast passenger liner.

Germany

The keel for Western Europe's first nuclear merchant ship the *Otto Hahn* was laid on September 17, 1963, in Kiel, West Germany. It was ordered by the Society for Nuclear Energy Utilization in Shipbuilding and Shipping. The ship is scheduled to begin operation in 1967. Its estimated cost is $12.5 million. The reactor chosen for this ship was an American design that is the direct derivation of the *Savannah* reactor.

Japan

Japanese industry and the Japanese government have designed a merchant nuclear submarine. The Marine Vessel Technology Laboratory of the Japanese Transportation Ministry and the Kobe shipyard of Kawasaki Heavy Industries are making an economic study of such a craft's performance capabilities. Japan is also building a nuclear oceanographic research vessel.

Scandinavia

Sweden and Norway have long maritime traditions. It is not surprising then that in September 1963 the two nations created a Norwegian–Swedish Nuclear Merchant Ship Project as a venture of the Norwegian Institute for Atomic Energy and the Swedish national atomic energy company,

Photo shows the USS Skate, *a nuclear-powered submarine, on the surface at the North Pole. The diagram (right) shows how a proposed merchant submarine tanker might be designed.*

Atomenergi AB. Norwegian and Swedish shipbuilders, shipping companies, and industry are sharing the estimated cost of $2 million. If results are favorable, construction of a nuclear ship could start in 1967.

Euratom

The European Atomic Energy Community* also is sponsoring research and development for nuclear ship propulsion equipment through contracts with companies in West Germany, The Netherlands, and Italy.

General studies of the design and operation of reactors at sea are being conducted by GKSS (Gesellschaft fuer Kernenergieverwertung in Schiffbau und Schiffahrt) near Hamburg. Euratom contributes 80% of the costs. The main investigation concerns shielding problems and the effects of ship movements on reactor operations.

Design of an advanced reactor for ships is being studied by RCN (Reactor Centrum Nederland) in association with Eindhoven Technical University at Petten, The Netherlands.

Relative merits of several types of reactors for propulsion of a large tanker were compared under a Euratom contract with the Italian Fiat and Ansaldo companies.

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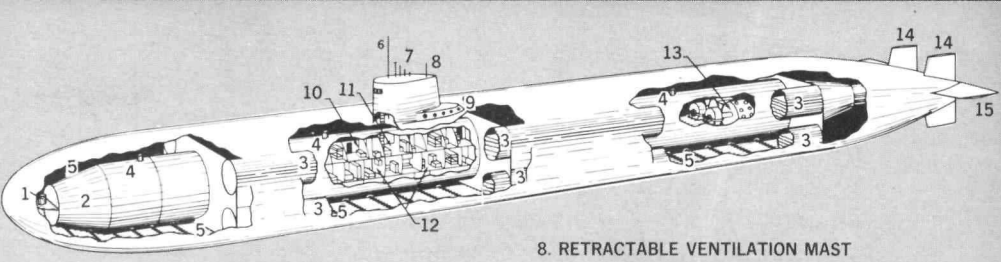
*Euratom is an international organization formed by Belgium, France, West Germany, Italy, Luxembourg, and The Netherlands to create conditions necessary for the speedy establishment and growth of nuclear industries.



1. NAVIGATING SONAR
2. TRIM TANK
3. VARIABLE CARGO TANK
4. ACCESS AND ESCAPE TRUNKS
5. MAIN CARGO AND BALLAST TANKS
6. PERISCOPE
7. RETRACTABLE ANTENNAS, RADAR AND RADIO
8. RETRACTABLE VENTILATION MAST
9. CARGO-PUMPING SHORE CONNECTIONS
10. OFFICERS' QUARTERS
11. CONTROL ROOM
12. CREW'S QUARTERS
13. ENGINE ROOM
14. RUDDER
15. DIVING PLANE

LOOKING AHEAD

Combining nuclear power with automated merchant ships that have special cargo-handling equipment can revolutionize the surface merchant fleets for the long, high-density trade routes. Looking further into the future, if costs of smaller nuclear reactors come down, nuclear energy could offer exciting advantages to smaller ships that service smaller, widely scattered ports.

Proponents of nuclear power agree that undersea craft would be subjected to fewer weather-caused stresses and strains and would avoid the loss of time and risk of damage suffered by surface ships in storms. Additionally, there is the expectation that submarines can open up the long sought Northwest Passage between the Atlantic and the Pacific Oceans.

The Arctic Ocean remains one of the last unknown areas. Even a few years ago an underwater trade route through the Arctic would have been considered only a subject of science fiction. Today it is a distinct possibility. The Navy's nuclear submarines *Nautilus*, *Skate*, and *Seadragon* have explored that ocean and have sounded out its passages. On historic cruises beneath the ice, they found that an underwater Northwest Passage does exist. Although the ice above may bar the routine passage of surface ships, beneath this barrier there is safe passage for nuclear submarines.

Commercial submarines traveling Arctic sea-lanes would greatly reduce the trading distances of the world. The pres-

ent route from Tokyo to London is 11,200 nautical miles; by polar passage it shrinks to 6500 miles. Likewise, a ship bound for Oslo, Norway, from Seattle via the Panama Canal sails 9300 miles, while a submarine navigating the Arctic shortcut would travel only 6100 miles.

Talk of a commercial nuclear submarine was revived in August 1963 by Phoenix Canada Oil Company, Ltd. This company, with interests in some 6 million acres in the Canadian Arctic, proposes to use submarine tankers to carry oil from northern Canada to Greenland for transfer to surface ships or for storage. Using a nuclear submarine would make it possible to market oil throughout the year.

No one can say how soon commercial nuclear submarines will sail from Alaska across the North Pole. But that day doubtless will come. Until then, more exploration is needed to see how ice conditions change with the seasons. When the first commercial cargo submarine does make its first voyage across the top of the world, it will depend on nuclear energy to run its engines.

Large air-cushion ships and hydrofoil vessels powered by nuclear reactors also have been proposed and theoretically have high potential for development. Nuclear tugs, liners, and bulk carriers also have been considered, and nuclear-powered ships to conduct undersea mining operations also have been proposed for the future.

Nuclear energy from fission in maritime reactors and nuclear energy from radioisotopes in instruments and underwater navigational aids soon will change life at sea, and man's endless contest with the restless waters will take a new and adventurous turn.

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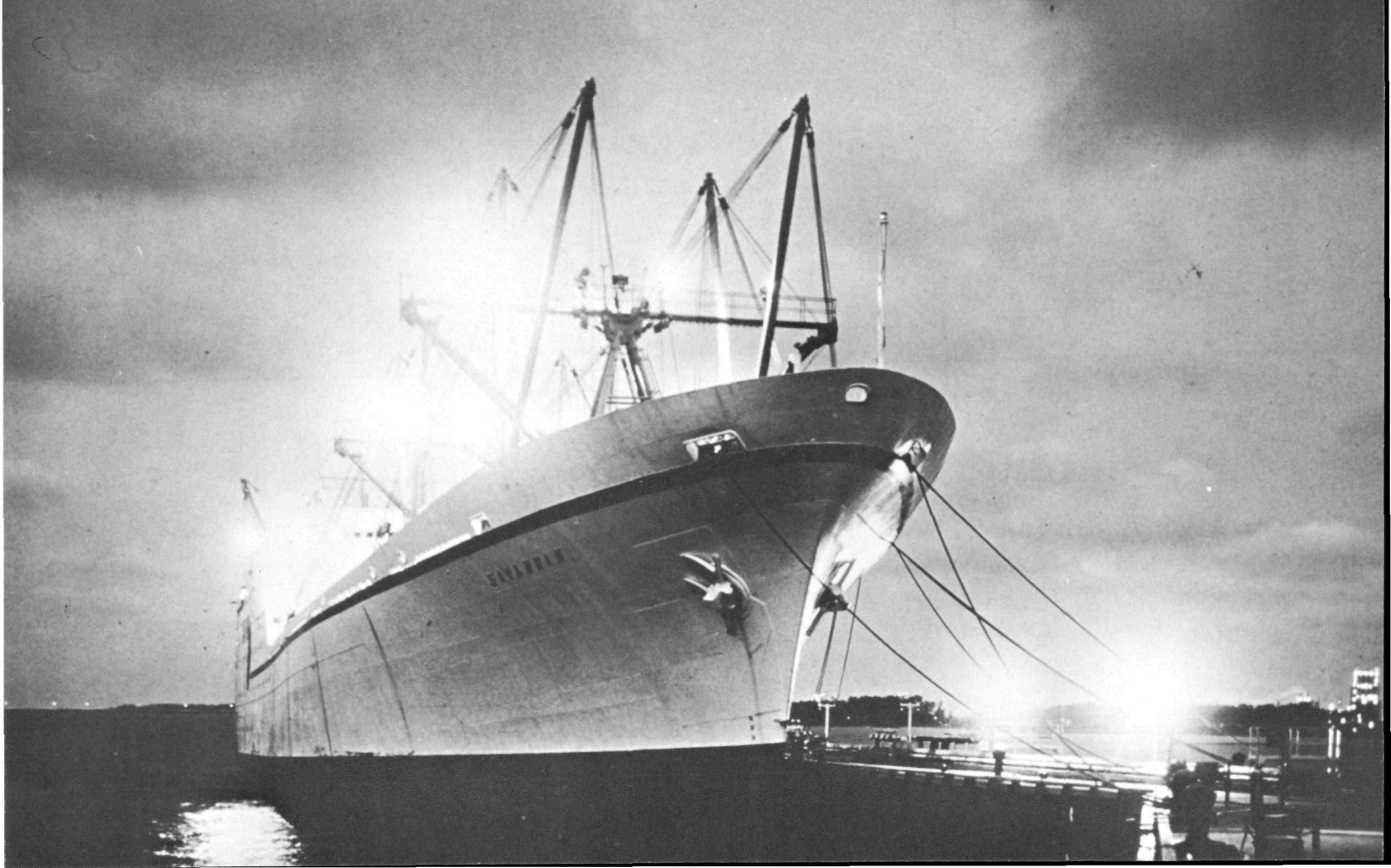
Full Speed Ahead, 15 minutes, color, 1958. Produced by the U. S. Maritime Administration and the Atomic Energy Commission. Depicts initial stages in development of the first U. S. nuclear-powered merchant ship, the NS *Savannah*. Includes industrial and technical procedures in building and testing the reactor, surveying of harbors, and laying the keel.

Under Way, 20 minutes, color, 1960. Produced by the U. S. Maritime Administration and the Atomic Energy Commission. Traces design and construction of the first U. S. nuclear-powered merchant ship, the NS *Savannah:* hull design and assembly; design, test, and fabrication of nuclear power plant; critical assembly used in core design; fuel-element fabrication; erection of reactor-system containment vessel; safety features.

The Nuclear Ship Savannah, 28½ minutes, color, sound, 1965. Produced by the U. S. Maritime Administration and the Atomic Energy Commission. This film describes the design, construction, sea trials, and initial port calls of the NS *Savannah*.



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Printed in the United States of America

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June 1968